Preventive methods of reduce Anterior Cruciate Ligament injuries

Sarvesh Sankar Dass

Abstract

Anterior Cruciate Ligament injuries are common among female athletes with 16% of them experiencing ACL injuries during their careers. This can cause physical and mental stress for athletes and potentially impact their careers. A consensus on which preventive interventions are most effective has not been reached, therefore gaining knowledge on the anatomy and physiology of the ACL is essential in finding different methods of preventing ACL injuries. Interventions focusing on various prevention methods are often used. We reviewed existing literature that focused on the four major prevention methods to reduce ACL injuries. Studies that tested these methods by conducting several experiments have been identified, and four major methods of preventing ACL injuries are being highlighted in this review. These include preventing the trunk from swinging while landing, preventing the knees from moving medially, using the correct lower muscles for absorption, and using all the lower extremities equally. These studies reported that the rate of an ACL tear was lower with adoption of the different types of interventions. In addition to these techniques, future studies should also focus on new methods to strengthen an athlete's ability to perform without a major risk of injury.

Introduction

Anterior cruciate ligament (ACL) injuries can change the trajectory of an athlete’s career by causing major damage to their physical and mental health along with incurring high healthcare costs. Annually, more than 200,000 ACL injuries occur in the United States (Gawande et al., 2019) with the majority occurring among the athletic and military population. Of these injuries, 70% result from a non-contact injury, while the remaining 30% arise from immediate contact with an individual. (Gawande et al., 2019). As many as 16% of female basketball players may experience an ACL injury during their careers, which is 2 to 4 times more frequent than male athletes (Taylor et al., 2015). Therefore, prevention of ACL injury by adopting the best techniques is vital to prevent adverse consequences.

Several studies have examined the utility of different techniques to reduce ACL injury and often recommend adoption of multicomponent preventative programs. In this review, we aimed to discuss the four major prevention methods of ACL injuries and interventions that have been proven to reduce injuries by enhancing strength, agility, balance and flexibility. These include interventions like core strengthening programs that often prevent the trunk from swinging while an athlete lands (Jeong et al., 2021). Interventions targeting to improve internal and external focus help athletes keep their knees from moving side to side while in the air (Dalvandpour et al., 2023). Perturbation exercises help the athlete absorb the landing using the correct muscles (Johnson et al., 2020). Different jumping techniques let the athlete use their lower extremities equally, decreasing the risk of ACL injuries (Newton et al., 2006).

Anterior cruciate ligament anatomy and physiology

ACL runs from the medial part of the anterior intercondylar area of the tibia to the lateral part of the posterior intercondylar area of the femur. The ACL helps stabilize the knee joint by preventing any excess forward movements of the tibia or knee rotations (Markatos et al, 2012). The mean length of the ACL is 32 mm (varies from 22-41 mm), and the mean width is 9.55 mm (varies from 7-12 mm) (Amis & Dawkins, 1991). It is a band-like structure comprising an organized collagen matrix, which accounts for 75% of its weight. The collagen comprises type I, which accounts for 90% of the total collagen. The rest of it is type III, which accounts for 10%. Fibroblasts, such as elastin and proteoglycans, form the other 25% of the weight (Clark et al, 2006). The ACL can be divided into three zones, proximal, middle, and distal.

The ACL has two bundles, the anteromedial and the posterolateral, which are named based on their tibial insertions. The anteromedial bundle originates from the proximal part of the femur and inserts into the anteromedial portion of the tibia. The posterolateral bundle starts from the distal part of the femur and inserts into the anteromedial portion of the tibia. The anteromedial bundle tightens, and the posterolateral bundle relaxes when the knee is flexed, and the opposite occurs when the knee is extended. (Peterson et al, 2006). Therefore, the two bundles- anteromedial and posterolateral maintain the anteroposterior and rotatory stability of the knee, respectively (Yasuda et al., 2011).

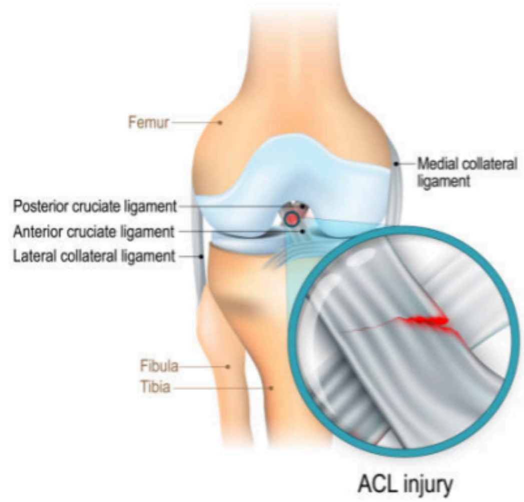

Figure 1. Anatomy and location ACL injury - The image shows a tear of the Anterior Cruciate Ligament.

Types of ACL tears

Four different types of tears have been reported previously (Sherman et al., 1991). However, recently, using MRI imaging which can identify even mild tears, a 5th type has been identified (Van der list et al., 2017). Type 1 tear occurs in the proximal part of the ACL. Type II tears are located in the proximal part, nearer to the center. Type III tears are located in the middle part. Type IV and type V tears both occur in the distal part, with type V being the most distal of all types (Van der list et al., 2017). In a pediatric and adolescent population study (Van Der List et al. ,2019), most of the tears were reported to be distal bony avulsions (type 5). Among 1 to 13 years, tears were equally likely to be proximal or distal and at the adolescent age (14-17 years), most tears were in the middle part (type III). They did not find sex and sports injury mechanisms to have a role in tear location distributions. On the other hand, the same investigators noted that among 353 patients who had an MRI scan with an ACL tear, 16% had type I tears, 27% had type II tears, 52% had type III tears, and only 3% had bony avulsion tears(Van Der List et al., 2019). These data inform surgeons about who may benefit from ACL preservation surgery vs ACL reconstruction, which is of interest in the pediatric and adolescent population.

Risk Factors of ACL injuries

There are both internal and external risk factors for ACL injuries. The external factors include many types of task specific demands and environmental conditions such as weather. The internal factors include the alignment of the lower extremity, the size of the notch between the femoral condyles, and the slope of the tibial plateau (Dai et al, 2012). The injury is more common in females, as the patterns of movements are riskier (McLean et al., 2008). Females often land in an extended posture, focusing more on the quadriceps which results in a modified muscle activation and more awkward knee motions than men. The incidence rates of ACL injuries per 1,000 athletes who played basketball were higher in females (female: 0.20 95% confidence intervals [0.16–0.25] vs male: 0.07 [0.05–0.08]. Notably, ACL injuries are more often seen in people participating in competition games than those participating in training (Stojanovic et al, 2022). ACL injuries are mostly a result of a non-contact injury, such as an excessive leg rotation and decreased knee flexion, where there is sudden deceleration and a movement involving landing and pivoting (Yu & Garrett, 2007).

Prevention methods for ACL tears and injuries

Four major methods have been identified to prevent ACL injuries. Neuromuscular training (NMT) forms the core elements of all the ACL prevention programs. NMT usually focuses on neuromuscular control, dynamic joint stability and optimizing movement patterns to reduce injury. Proven preventive methods include preventing the trunk from swinging medially, preventing the knee from moving medially while landing, using the correct muscles for absorption, and landing equally with all the lower limbs (Hewett et al., 2010). Multiple interventions and studies have demonstrated that these methods help decrease the risk of ACL injuries and help athletes have a long and successful career.

Preventing trunk from swinging medially: Preventing the trunk (chest, abdomen, pelvis, and back) from swinging medially is one of the movements that can prevent ACL injuries. As someone moves, the trunk needs to be stabilized and should not move as the person is landing, which can be accomplished by strengthening the core. Jeong et al. (2021) performed a study to test the validity of core-strengthening interventions to prevent ACL injuries. The participants were enrolled in a 10-week core strengthening program and followed a specific study protocol. The protocol consisted of jogging 1.3 km, followed by core strength training and stretches for 15 minutes. The study showed that the endurance of the trunk in the intervention group was significantly higher than the control group ($p<0.05$). This caused changes in the biomechanical outputs, such as the force put on the knee and the hip abduction angle and suggested that these interventions could decrease ACL injuries.

Similarly, Parsons et al. (2012) performed a study to test if verbal and visual feedback improved jump-landing kinematics in young girls. The girls were given verbal and visual feedback to see if it improved their jump-landing kinematics. No difference between the landing mechanics was found with this method; however, the statistical analysis showed a difference between the two groups in terms of maximum flexion of their hips suggesting some potential benefits with this intervention. Various interventions have shown that preventing the trunk from swinging medially can help prevent ACL injuries. Athletes can use any of these interventions based on the accessibility to resources.

It is also important to note that this type of intervention is not always successful. For example, Zebis et al. (2016) also performed a study testing the core strength and its effect on ACL injury prevention. Using an NMT program, this study also tested the usefulness of core strengthening interventions. The program included exercises that involved wobble boards, balance mats, and balls. The program led to a 43% [95% CI: 32%-55%] difference in the EMG (electromyography) measurement of the pre-activity of the vastus lateralis and semitendinosus when compared to the control group. However, no recorded differences were found between the kinetic and kinematic variables showing any potential clinical benefits. More experimental research using the NMT programs to show a direct correlation between the program and a decree in ACL injuries are needed.

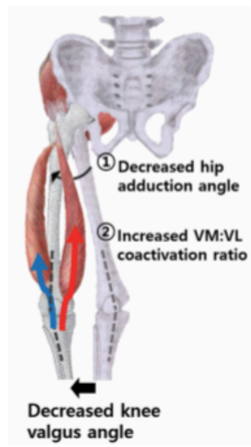

Figure 2. Preventing medial movement of the trunk causes less knee valgus- The image shows how a decreased hip adduction angle leads to a higher Vastus Medialis to Vastus Lateralis activation ratio, resulting in less knee valgus (Jeong et al. 2021)

Preventing the knee from moving medially: As an athlete lands, they must ensure that their knees are not moving inward, reaching a knock-knee position. As the knee starts to move medially, this causes a low knee flexion angle. A low knee flexion angle has been linked to higher anterior tibial shear force, which increases stress on the ACL (Parsons et al., 2012). Parsons and colleagues (2012) also showed that focusing on keeping the knee from moving medially can decrease the injury rate of the ACL. In the study, from week 1 to week 2, the angle of the left knee flexion increased from 71.9 to 89 degrees. The right knee flexion also increased from 42.2 to 63.4 degrees. In their conclusion, they emphasize that an increase in knee flexion decreases higher anterior tibial force, which leads to less strain on the ACL (Parsons et al., 2012).

Dalvandapour et al. (2023) also studied whether attention during ACL injury prevention exercises improves jump landing kinematics. The study had 3 groups that used the Prevent

Injury and Enhanced Performance (PEP) program, with one group using an external focus (EF) of attention, one group using the Internal Focus (IF) of attention, and a control group. The study showed a higher knee flexion angle in the groups that used EF which led to a decrease in the ACL injuries, and an improvement in the jump landing kinematics. These two studies with different intervention methods have shown the importance of an athlete keeping their knee from moving medially as they land. These interventions can be easily implemented with the need for minimal resources.

Figure 3.Knock kneed position- The figure shows a common risk factor of ACL injury, where the knee moves medially, creating the Knock Kneed position. (Acevedo et al., 2014)

Using correct muscles for absorption: While landing, an athlete must use all the lower limb muscles to absorb landing on the ground. If too much pressure is exerted on one muscle, then the likelihood of an ACL injury increases. Johnson et al. (2020) performed a study testing this theory by comparing two prevention programs. Participants included female athletes who had previous ACL injuries and were randomized to one of two prevention programs: strengthening, agility, plyometric, and prevention (SAPP), or SAPP plus perturbation training (SAPP+PERT). SAPP+PERT exercises used a platform/roller board combination, unilateral stance on a roller board, and unilateral stance on a tilt board. The therapist created individual perturbations by moving the equipment across multiple planes. The study results demonstrated that neither program outperformed the other, and an equal number of participants had a retear following the intervention. When retear risk was evaluated in participants from both the SAPP and SAPP+PERT training programs, contralateral ACL injury risk decreased when compared to standard rates. This lower rate of ACL injuries was attributed to an emphasis on proper landing technique and movement patterns during agility, plyometric, and performance activities.

Furthermore, a study by Bonato et al. (2017) also tested the effect of the NMT program and the effect of strengthening the ACL and the muscles adjacent to the ligament. Seventeen international players from the premier Italian national league were chosen to participate. The program consisted of “general activation exercises, mobility exercises, strength exercises, plyometric exercises, and agility exercises,” which significantly helped increase the strength of the lower limbs used for landing in these athletes. The effect of increasing muscular strength and stability of the ACL was clearly demonstrated, as the experimental group had none with ACL lesions after the intervention. In contrast, the control group had 7 people with ACL lesions at the end of one standard season. These lesions were assessed by physicians and captured using an electronic method. As the study showed, the more an athlete can focus on increasing the strength of the ACL, the less the risk of injury is. The more strength an athlete builds in the muscles near the ACL, the easier it is for the absorption to be equivalent.

Using the correct muscles for muscle absorption has been shown to be a plausible prevention method that does not require many resources. However, some inconsistencies in this data and experimentation indicate that further research is needed to clarify the magnitude of positive impact of these types of interventions.

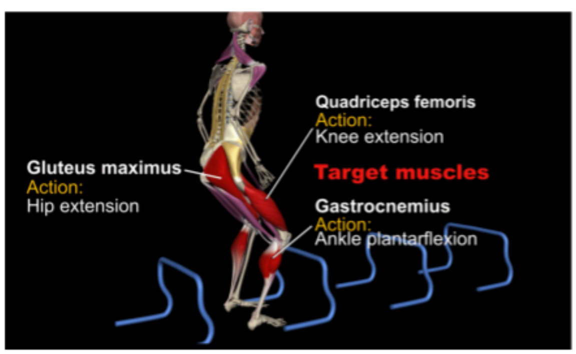

Figure 4. Correct muscles used for landing- The image shows how each muscle is used while an athlete is landing.

Using all lower extremities equally: As athletes prepare for landing, they should focus on using all their lower extremities equally. A study performed by Newton et al. (2006) demonstrated how muscle imbalances can cause injuries among collegiate athletes when using their lower muscles equally. Fourteen Division one softball players were subjected to peak torque measures for isokinetic flexion and extension at 60 and 24 degrees. Also, measures of the maximum and average force put on each leg during parallel back squats, vertical jumps using two legs, and the athletes' performance in a 5-hop test were tested. Marginal differences between 4.2% and 16% were seen for all the measures except for the average force put on each leg. This study proved that a significant number of collegiate athletes also suffer from muscle imbalances, which can cause them to land improperly and increase the injury rate.

Fox et al. (2023) conducted a meta-analysis testing the effect of inter-limb asymmetry on different aspects of athletic performance. To display the findings, the paper included forest plots, showing the effects of lower-limb asymmetry on different outcome variables. Study results showed the negative effect of inter-limb asymmetry on sprinting performance. This analysis suggests that lower-limb asymmetry directly correlates with the sprinting performance of many athletes, which could cause major injuries due to non-contact motion. As most ACL injuries occur from non-contact movements, usually with very slight motions, the meta-analysis' findings highlight the dangers of lower-limb asymmetry in relation to ACL injury rate.

To provide suggestions for addressing lower limb imbalances, Bishop et al. (2018) reviewed the best exercises and training programs to decrease asymmetry and highlighted a study by Sannicandro et al. (2014), which used an experimental group and a control group of youth tennis players. The experimental group underwent different methods, and the asymmetrical change was recorded. The single-leg hop proved to be the most effective of the different methods, bringing down the asymmetric change from 9.0% to 3.7%. They also discussed a study by Gonzalo-Skok et al. (2017) with two groups: a group focused on unilateral exercise (focusing on one leg at a time) and a group focused on bilateral exercises. After both groups completed similar training programs, the differences were recorded. The results from the unilateral groups showed major differences between the asymmetry in the lower limbs after the program. The rate of asymmetry dropped from 9.6% to 4.8%. These studies reinforced that the asymmetry of the lower limbs is likely to be better in those athletes focusing on training one leg at a time.

Figure 5. Uneven usage of lower extremities - The figure shows an uneven landing where the usage of the knee and the hip is not even. (Getgood et al. 2017)

Figure 6. Summary of different interventions, with the results and benefits noted.

Study	Intervention	Results	Benefits noted
Jeong et al. (2021)	1.3 km jogging followed by core strength training and stretches for 15 minutes each for 10 weeks	Intervention group had a higher trunk endurance score than the control group ($p<0.05$).	Preventing the trunk from swinging while movement; Using all lower extremity muscle equally
Parsons et al. (2012)	One session of video and verbal feedback to improve jump landing kinematics in adolescent girls	The angle of right knee flexion increased from 42.2 to 63.4 degrees, and the angle of left knee flexion increased from 71.9 to 89 degrees.	Preventing the knee from moving medially; preventing the trunk from swinging while moving

Bonato et al. (2017)	7 international players were chosen to participate in a program that used exercises that focused on general activation, strength and mobility, and agility and plyometrics.	The experimental group didn't have any players suffering from ACL lesions, and the control group had 7 players suffer from ACL lesions at the end of one standard season.	Using correct muscles for absorption; using all lower extremity muscles equally
Johnson et al. (2020)	Perturbation exercises using a platform/roller board combination, unilateral stance on a roller board, and unilateral stance on a tilt board, each with therapist perturbations in multiple planes	There was a 43 % [CI: 32%-55%] difference in the EMG measurement of the pre activity of the vastus lateralis semitendinosus when compared to the control group.	Using correct muscles for absorption; Using all lower extremity muscles equally
Newton et al. (2006)	Parallel back squats and vertical jumps using two legs, and the force put on both legs were measured	Significant differences were found for all the measures between 4.2% and 16%, except for the average force put on each leg.	Using all lower extremity muscles equally

Guideline recommendations

National Athletic Trainers Association position statement on prevention of ACL injury recommends participation in multi-component training programs that include feedback regarding technique and at least three of the exercise categories (Padua et al., 2018). They recommend that athletes should focus on strength, plyometrics, agility, balance and flexibility to reduce non-contact and indirect contact ACL injuries during physical activity.

Conclusion

ACL injuries are a common problem that can have serious physical and mental consequences, especially among female athletes. Literature suggests the potential benefits of four important preventative techniques—stabilizing the trunk, reducing medial knee movement, maximizing muscle absorption, and ensuring equal use of the lower extremities. Interventions that use targeted exercises, core strengthening exercise, and neuromuscular training are recommended as multiple studies have proven these interventions as the most effective in lowering ACL injuries. By incorporating these techniques into training plans, athletes can increase performance, avoid injuries and extend their careers. Future studies should attempt to improve these techniques and make them available to a wider range of sports and populations along with identifying additional new methods to prevent ACL injuries.

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